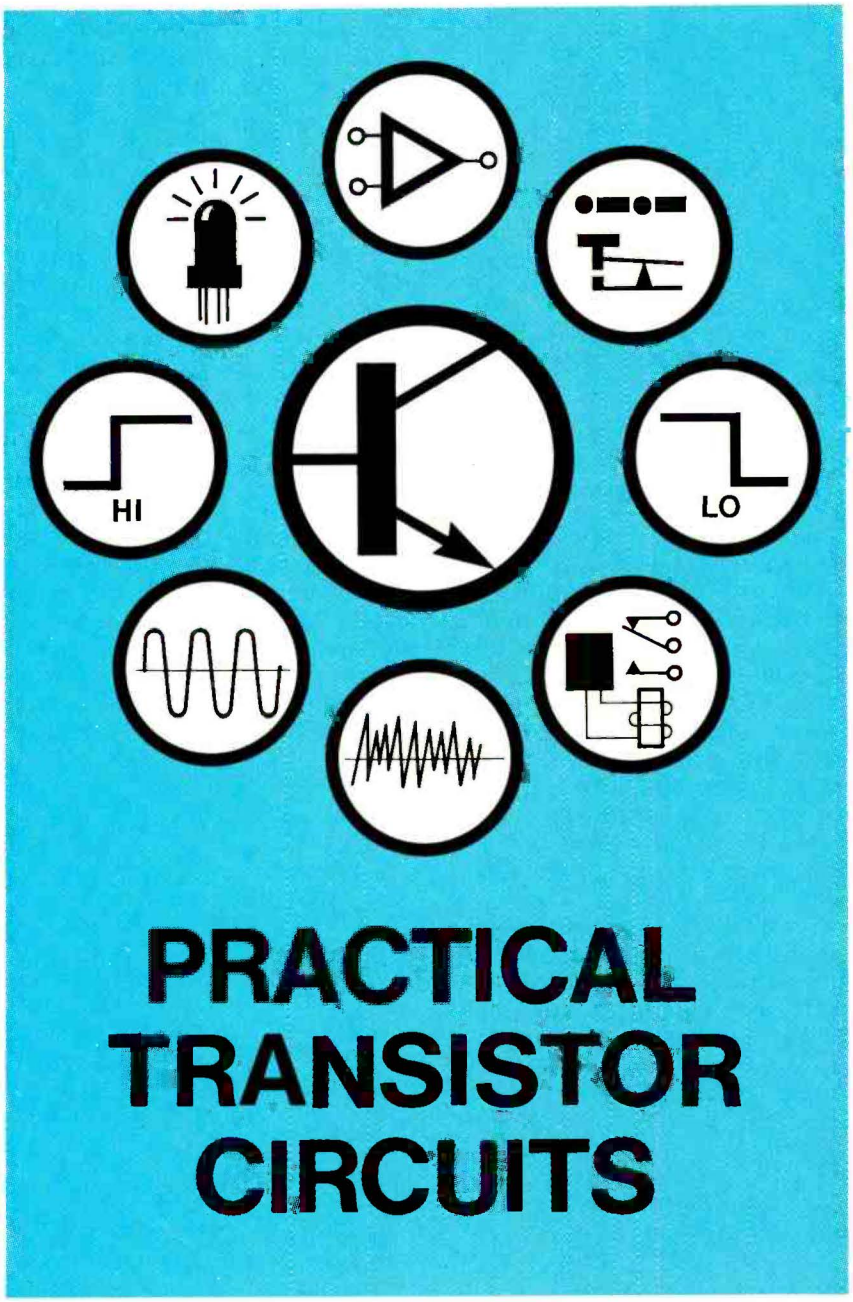
RAY MARSTON



PRACTICAL TRANSISTOR CIRCUITS

Build these circuits that can amplify, filter, generate white noise, flash lamps, locate hidden metal—and perhaps even detect lies.

THIS LAST ARTICLE ON BIPOLAR junction transistors (BJT) is a potpourri of circuits. Some are practical and some are not so practical, but they can be great fun for experiments. With these circuits you can amplify signals, filter high and low frequencies, generate white noise, and flash lamps. You can also boost DC voltage levels, locate hidden metal objects, and detect rising water. One circuit will even demonstrate the fundamentals of lie detection!

Last month's article concentrated on the operating principles and design options for audio power amplifiers. Earlier topics in this series have included descriptions and schematics for low-power amplifiers, preamplifiers, tone-control circuits, multivibrators, and various oscillators.

More power amplifiers

Today the easiest way to build a low- to medium-power audio amplifier is to pick an integrated circuit amplifier from a manufacturer's data book and supplement it with additional components recommended in the applications notes in the data book. However, if you just want to learn amplifier principles by experimentation or you have a simple application in mind, you should build the amplifier with discrete transistors.

Figure 1 is a schematic for a general-purpose, low-power, high-gain amplifier based on discrete transistors. A Class A amplifier, it can drive a load such as a speaker or headset with an impedance greater than 65 ohms. The amplifier draws a quiescent current of about 20 milliamperes. However, this drain can be reduced by increasing the value of R3.

Transistors Q1 and Q2 are configured as common-emitter amplifiers: the output of Q1 is directly coupled to the input of Q2. This circuit has an overall voltage gain of about 80 dB. Notice that resistor R3, the emitter load of Q2, is decoupled by capacitor C3 so that the Q2 emitter *follows* the average collector voltage of Q1.

The base bias for Q1 is derived from Q2's emitter through R2. With this configuration, the bias is stabilized by negative DC feedback. Input potentiometer R4 serves as the circuit's volume control.

Figure 2 is the schematic for a simple, three-transistor, Class AB complementary amplifier which can drive about 1 Watt into a 3-ohm speaker load. Transistor Q1, which is configured as a common-emitter amplifier, drives a load that is the sum of speaker SPKR1, resistor R1 and potentiometer R5. Its output voltage is *followed* and boosted in power by the comple-

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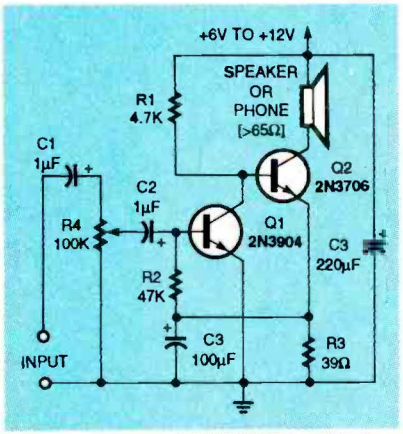

FIG. 1—AUDIO AMPLIFIER with two transistors offers high gain.

mentary emitter-follower stage made up of Q2 and Q3.

The output of the amplifier is fed through capacitor C2 to the junction of SPKR1 and R1 where it provides a low-impedance drive for SPKR1. It simultaneously bootstraps the value of R1 so that the circuit has high-voltage gain. The output is also fed back to Q1's base through R4 so that it produces a base bias through a negative feedback loop.

Carefully adjust trimmer potentiometer R5 to minimize audible signal crossover distortion so that it is consistent with lowest quiescent current consumption that can be measured. To obtain a reasonable value, set the quiescent current from 10 to 15 milliamperes.

Figure 3 shows a more complex audio power amplifier that can deliver about 10 watts into an 8-ohm load when powered from a 30-volt supply. This circuit includes four, high-gain, quasi-complementary output stages (Q3 to Q6). Transistor Q1 functions as an adjustable *amplified diode* output biasing device in this circuit.

The main load resistor R2 of the Q2 common-emitter amplifier stage is bootstrapped by C2 and DC biased by R3. This network should set the quiescent output voltage at about half the power supply value. If it does not, alter the value of R3. The upper frequency response of the amplifier is restricted by C3, which enhances circuit stability. In addition, capacitor C5 is wired in series with R8 across the output of the amplifier to increase circuit stability. The amplifier should be set up initially as was described for the circuit in Fig. 2.

Scratch/rumble filters.

Today, with the widespread acceptance of compact discs (CDs), 33⅓ rpm long-playing (LP) and 45 rpm records are considered to be obsolete. Nevertheless, many people still own large collections of these records, and when played on quality record players, they can still provide many hours of listening pleasure.

Back when those records were popular, unless the record player amplifiers were properly filtered, scratch and rumble noises could interfere with reception. This interference was even more evident in the playing of older 78 rpm discs. While scratch and rumble are no longer universal problems, the techniques for eliminating them are still interesting.

Scratch noise is essentially sound at a frequency greater than 10 kHz picked up from the disc's surface, while *rumble* is sound at a frequency typically less than 50 Hz caused by variations in turntable drive motor speed. Each of these noises can be effectively eliminated or attenuated by passing the audio output from the record player through a filter that rejects the annoying parts of the audio spectrum.

The rumble filter in Fig. 4 is a high-pass filter that provides unity voltage gain for all frequencies greater than 50 Hz. However, it provides 12 dB per octave rejection to all frequencies below 50 Hz. For example, attenuation is 40 dB at 5 Hz. Transistor Q1 is configured as an emitter-follower biased at about half the supply value from the low-impedance junction formed by resistors R1 and R2 in parallel with capacitor C3.

However, negative feedback applied through the filter network of R3, C2, C1, and R4 causes an *active* filter response. The rolloff frequency of the circuit can be altered, if desired, by changing the values of capacitors C1 and C2—provided that they are kept equal. For example, if the values of C1 and C2 are reduced 50% from 0.220 to 0.110 microfarads, the rolloff frequency will be doubled to 100 Hz.

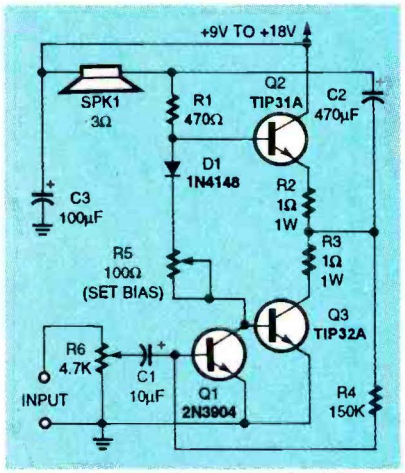

FIG. 2—AUDIO POWER AMPLIFIER with three transistors has a 1-watt output.

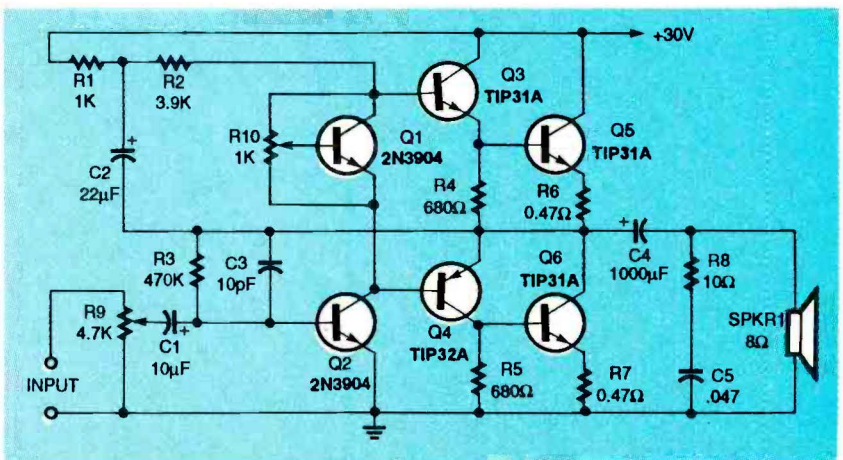

FIG. 3—AUDIO POWER AMPLIFIER WITH SIX TRANSISTORS has a 10-watt output.

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The scratch filter circuit of Fig. 5 acts as a low-pass filter that provides unity voltage gain to all frequencies below 10 kHz, but it rejects all frequencies above 10 kHz at 12 dB per octave. This circuit resembles Fig. 4 except that the positions of the resistors and capacitors are transposed in the network consisting of C2, R4, C4, and R5.

The rolloff frequency of that circuit can be altered, if desired, by changing the values of C2 and C4. For example, if both are increased from 0.0022 to 0.0033 microfarads, the rolloff frequency is reduced from 10 kHz to 7.5 kHz.

The circuits of Figs. 4 and 5 can be combined to make a composite scratch and rumble filter. The output of the high-pass filter is connected to the input of the low-pass filter. If desired, bypass switches can be installed in the individual filter sections so that the filters can easily be switched in and out of circuit. This change is illustrated schematically in Fig. 6.

It's worth noting that if the circuits of Figs. 4 and 5 are built on a single board, three components can be saved by making the biasing network composed of resistors R1 and R2 and capacitor C3 common to both filter circuits.

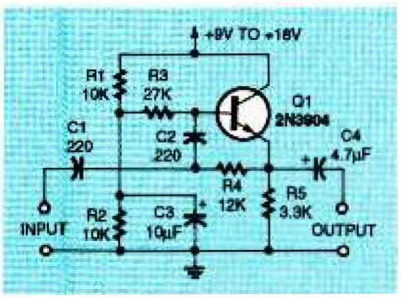

FIG. 4—HIGH-PASS FILTER eliminates 50-Hz record player "rumble".

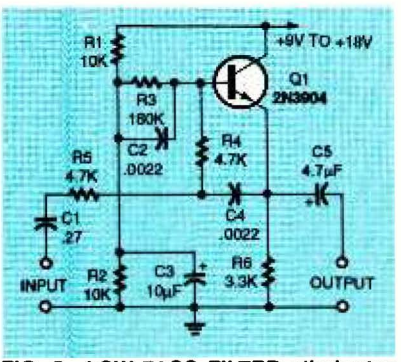

FIG. 5—LOW-PASS FILTER eliminates 10-kHz record player scratch noise.

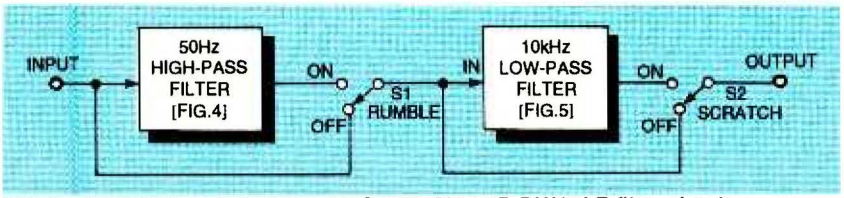

FIG. 6—COMPOSITE SWITCHABLE SCRATCH AND RUMBLE filter circuit.

Noise circuits

White noise is a steady hissing sound obtained by mixing a full spectrum of randomly generated audio frequencies, each having equal sound power when averaged over time. White noise can be heard by tuning an FM radio receiver to that part of the band where no nearby stations can be heard. It is intentionally generated for testing audio- and radio-frequency amplifiers. It can also be an effective sleep aid because it masks random background noises from voices, passing vehicles, car horns, closing doors, and other sources.

Figure 7-*a* is the schematic for a simple but useful white noise generator based on the inherent white-noise generation capability of a reverse-biased Zener diode. In this circuit, resistor R2 and Zener diode D1 form a negative-feedback loop between the collector and base of common-emitter amplifier Q1.

This loop stabilizes the DC working levels of the circuit, and capacitor C1 decouples the AC. As a result, D1 becomes a white-noise source in series with the base of the Q1, which amplifies that noise to a useful level of about 1 volt, peak-to-peak.

The base-emitter junction of any silicon transistor can function as a noise-generating Zener diode if its junction is reverse-biased to its breakdown level. This breakdown typically occurs in a 2N3904 small-signal BJT at about 6 volts. Figure 7-*b* shows the schematic of a two-transistor, white-noise generator. In this circuit Q1 acts as a Zener diode.

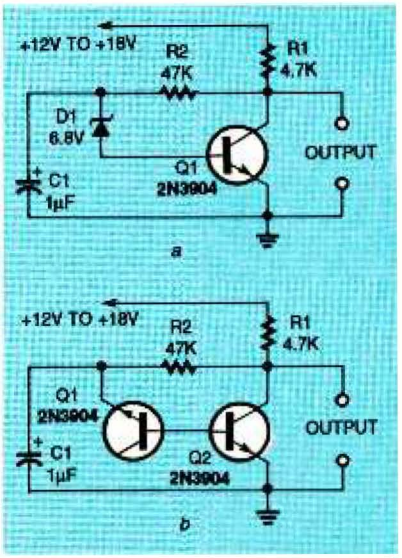

FIG. 7—WHITE NOISE GENERATORS with a transistor and Zener diode (*a*), and one with two transistors (*b*).

Audio noise can be annoying, especially if you are trying to listen to a very weak broadcast station. You might find that the peaks of unwanted background noise completely swamp the broadcast signal, making it unintelligible. It is possible to overcome this problem with the *noise limiter* circuit shown in Fig. 8.

In this circuit, both the signal and the noise are fed to amplifier Q1 through potentiometer R3. Transistor Q1 amplifies both waveforms equally, but diodes D1 and D2 automatically limit the peak-to-peak output swing of Q1 to about 1.2 volts. If R3 is adjusted so that the signal output is amplified to this peak level, the noise peaks will not exceed signal output. Therefore, the received signal will be far more intelligible.

Astable multivibrators

The *astable multivibrator* or *square-wave generator* circuit is versatile. Figure 9, for example, shows how it can flash two light-emitting diodes (LED) about once per second. Its flash rate is controlled by the time-

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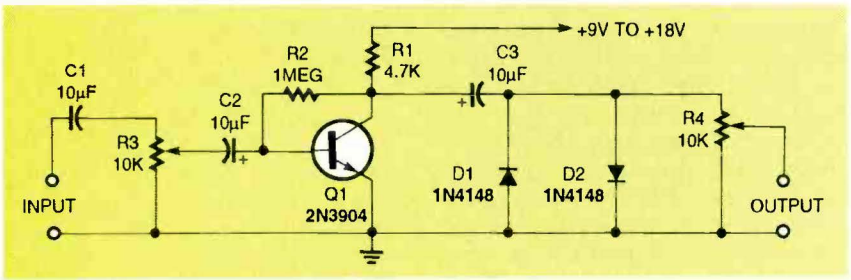

FIG. 8—NOISE LIMITER CIRCUIT improves the reception of weak broadcast stations.

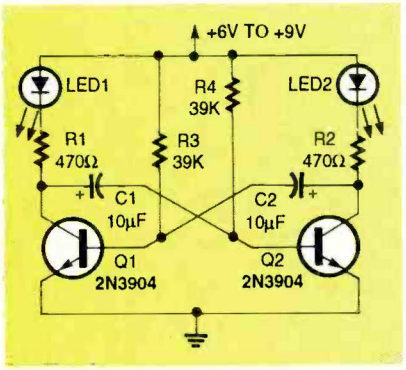

FIG. 9—TWO-LED FLASER circuit can attract attention.

constant values of resistive-capacitive combinations of R4 and C1 and R3 and C2.

The LEDs are in series with the collectors of transistors Q1 and Q2, and they flash on and off symmetrically out-of-phase with each other. The flash rate can be changed by altering the values of either R4 and C1 or R3 and C2. You can also replace one of the LEDs with a short circuit to make the circuit a one-LED flasher.

Figure 10 is a simple variation of the Fig. 9 astable multivibrator. This circuit generates an asymmetrical waveform at about 800 Hz, which is fed to speaker SPKR1 and limiting resistor R_X in the collector circuit of Q2. A monotone audio signal is generated when switch S1 is closed.

This circuit becomes a simple sound generator if S1 is a simple on-off switch, or it can be a Morse-code practice oscillator if a telegrapher's key is substituted for S1. The frequency of the generated tone can be changed by altering the values of either or both capacitors C1 and C2.

Figure 11 shows how an astable multivibrator can act as a signal injector-tracer for testing radio receivers. When S1 is in the INJECT position 1, transistors Q1 and Q2 are configured as a 1-kHz astable multivibrator. With that setting, a sharp squarewave signal is sent to the PROBE terminal through R1 and C1.

That waveform, which is rich in harmonics, will produce an audible output through a radio's loudspeaker if it is injected into any audio- or radio-frequency stage of an amplitude-modulated radio. By selecting a suitable injection point, the injector can help in troubleshooting a defective radio.

When S1 is switched to TRACE position 2, the circuit is configured as a cascaded pair of common-emitter amplifiers. The PROBE input feeds the base of Q1 and Q2's output driving headphone Z1. Consequently, any weak audio signal fed to the PROBE will be amplified directly and heard in the headphone.

Similarly, any amplitude-modulated radio-frequency signals that are fed to the PROBE will be demodulated by the nonlinear response of transistor Q1, and the resulting audio signal will be amplified and heard in the earphone. If the PROBE is connected at suitable test points in a radio, the tracer can troubleshoot faults.

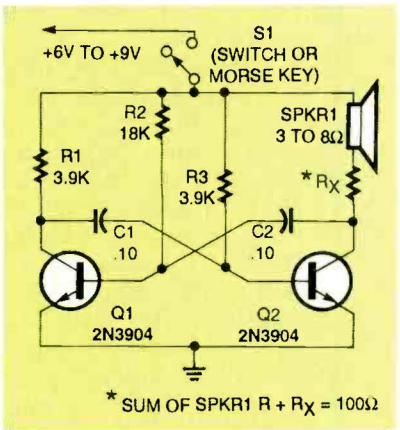

FIG. 10—MORSE-CODE PRACTICE oscillator is a multivibrator with a telegrapher's key.

LC oscillators.

Many applications can be found for inductance-capacitance (LC) oscillators in test equipment and practical circuits. Figure 12 is a *local oscillator* or *beat-frequency oscillator (BFO)*. Transistor Q1 is configured as a conventional Hartley oscillator with a modified 465 kHz intermediate frequency transformer as its collector load.

If the internal tuning capacitor of the transformer is removed, variable capacitor C1 becomes the tuning control of a variable-frequency oscillator. The output frequency can be varied from well below 465 kHz to well above 1.7 MHz.

Any radio capable of receiving broadcast band frequencies will detect the oscillation frequency if it is placed near the signal generator circuit. If the signal generator is tuned to the inter-

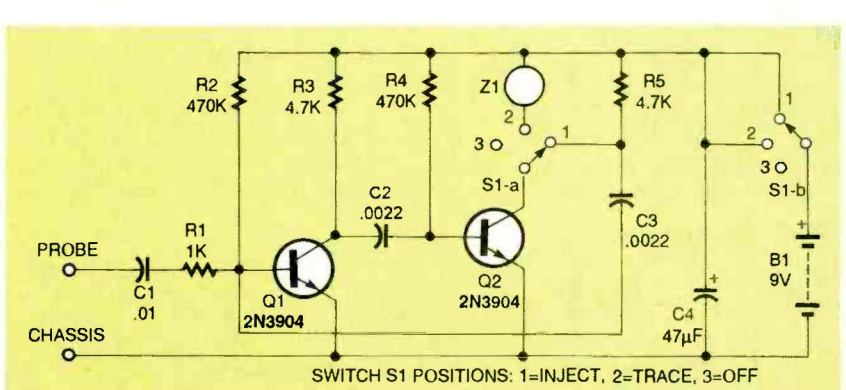

FIG. 11—AUDIO-RADIO SIGNAL INJECTOR and tracer will help in troubleshooting ailing radios.

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mediate frequency of a radio, a beat note can be heard. This will permit continuous-wave or single-sideband transmissions to be detected.

Figure 13 is a modification of Fig. 12 without a transformer secondary. When the circuit is functioning with a nearby radio receiver acting as a detector and amplifier, it becomes a simple metal object locator. Oscillator coil L1 is made by winding 30 turns of wire tightly on a 3- to 4-inch diameter plastic core or bobbin about 1 inch long. It becomes a *search head* or *sensing coil* when it is connected to the circuit with a 3-wire cable.

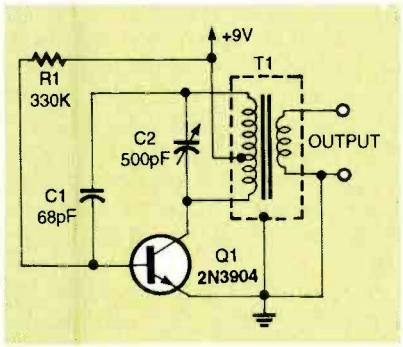

FIG. 12—BROADCAST BAND SIGNAL generator/ beat-frequency oscillator.

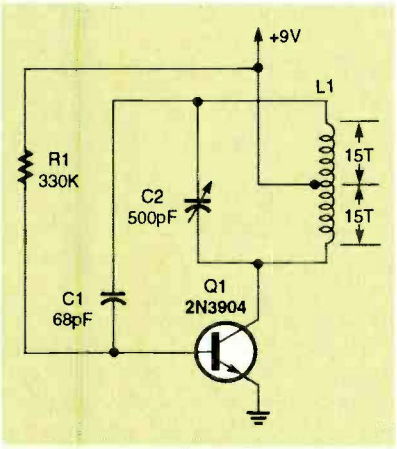

FIG. 13—METAL OBJECT locator can hunt for hidden metal pipes or wires.

The search head or sensor can be mounted at the end of a long wooden or plastic handle if you want to use the circuit as a classic ground-sweeping metal detector. Similar circuits can detect buried treasure or military mines that include at least some metal parts. However, the complete circuit can be housed in a handheld case if you want to locate metal pipes or wiring that are hidden behind walls that are made of brick, wood, or plasterboard.

The operation of the object locator circuit in Fig. 13 depends on the presence of a metal object that will interfere with coil L1's electromagnetic field. The interfering object changes both the inductance value of L1 and the frequency of the field. The presence of the metal object can be detected by a battery-portable broadcast band radio held close to the locator circuit. It senses the frequency shift and gives out an audible screech.

To detect a hidden metal object, first tune the radio to a local station, and then adjust C1 so that a low-frequency *beat* or chirp is heard from the radio's speaker. This beat note will change significantly if the locator circuit is placed near the hidden metal object.

Figure 14 shows the Hartley oscillator used as a DC-to-DC converter. It is capable of converting the output of a 9- volt battery to 300-volts DC. Transformer T1 is a 9-0-9-volt to 250-volt transformer. Its primary forms the inductance (L) part of the oscillator.

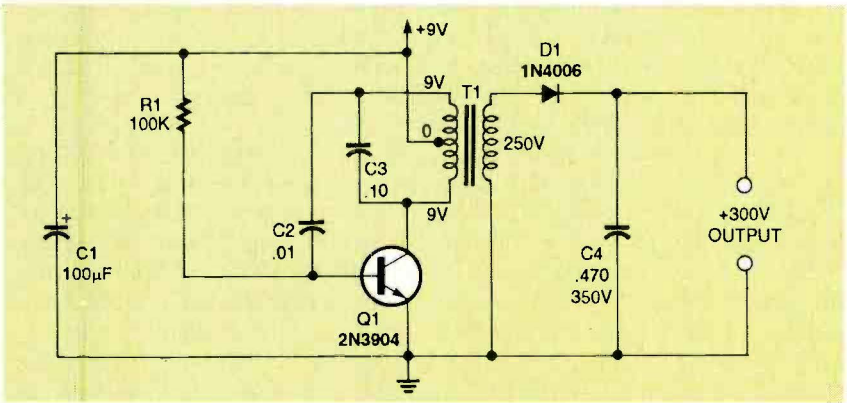

FIG. 14—DC-to-DC CONVERTER CIRCUIT BOOSTS 9 volts to 300 volts.

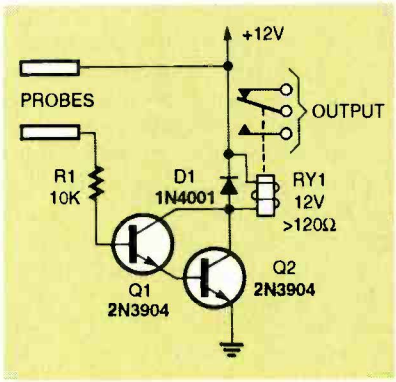

FIG. 15—RELAY CIRCUIT IS activated when probes are immersed in water.

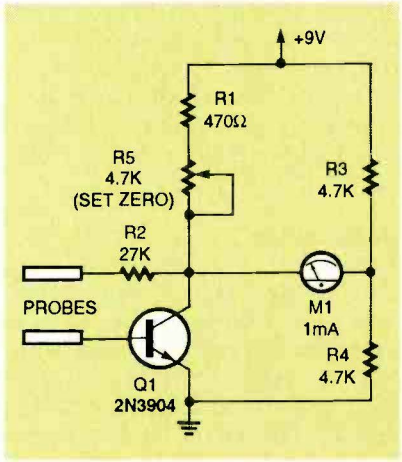

FIG. 16—SIMPLE "LIE DETECTOR" circuit is suitable for experiments and fun.

The supply voltage is stepped up to a peak of about 350 volts at T1's secondary. This waveform is rectified by half-wave rectifier diode D1, and it charges capacitor C4. With a permanent load, the output falls to about 300 volts at a load current of a few milliamperes. *Caution:* Without a permanent load across C4, the capacitor can deliver a powerful but nonlethal shock to the unwary.

Conductive water switch

A relay switch in a circuit that can be activated when a pair of probes come in contact with water can be very useful around the home or on a boat. It might, for example, indicate flooding of a basement, or water in the bilges of a boat. Figure 15 is a conductive-water-operated relay. Transistors Q1 and Q2 are a Darlington pair configured as a common-emitter, and relay coil RY1 is the collector load.

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The circuit relay is normally open (NO), but it is activated when the probes are placed across a resistance path that has a value generally less than several megohms. Most potable tap water has a bulk resistances below this value, so this circuit will work as a water-level relay switch. Relay RY1 can activate a pump or alarm. However, the presence of salt in the water (or sea water) has higher conductivity, and it can enhance the effectiveness of the detection circuit.

Because the conductivity of human skin has about the same resistance range as ordinary tap water, placing the probes in contact with human skin can also serve to activate the relay.

Lie detector

Figure 16 is a simple Wheatstone bridge "lie detector." However, because of the possible errors in the output of this circuit, its use should be confined to games or informal experiments. The circuit's operation is based on the knowledge that the resistance of human skin changes as a result of changes in the emotional state of the subject.

The bridge of this detector circuit is formed by resistor R1 and potentiometer R5 in one arm, R3 in a second arm, R4 in a third arm, and transistor Q1 (with a probe in its base circuit) in the fourth arm.

A milliammeter with its zero point at the center of the scale is connected across the bridge. It serves as a bridge-imbalance detector. Resistor R2 in series with the second probe is attached to the junction between Q1's collector and the low side of potentiometer R5. Large bare copper bars or silver spoons can be used to make suitable probes.

The probes should be taped or strapped directly to the skin on the subject's hand or arm, separated by at least several inches. When the subject is relaxed and his or her skin resistance reaches a stable value, adjust potentiometer R5 to obtain a null on milliammeter M1. The subject can then be questioned about the truth or falsity of emotionally loaded or embarrassing subject—in fun, of course.

The subject's skin resistance will change in response to questions of that kind if they are phrased correctly. The bridge should be unbalanced if the subject reacts emotionally to the questions. Experiments of this kind are often performed by students taking college-level experimental psychology lab courses, but the equipment that they use is usually more sophisticated and sensitive than this circuit.

Professional lie detectors typically factor in changes in the subject's respiration and pulse rate measured by other sensors to supplement the skin-resistance changes. The output of the machine is in the form of pen traces on a moving paper strip. Nevertheless, you might be surprised with the results you get experimenting with this simple circuit. Ω

NEW LITERATURE

continued from page 29

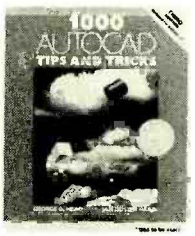
ate, audio, video, and radio frequencies. You will also find linear and switching power supplies, digital, and optoelectronic circuits. Moreover, amplifiers, regulators, oscillators, and signal waveform generators are covered. And you'll find information on voltage-to-frequency, analog-to-digital and digital-to-analog conversion, temperature sensing, and machine control.

All the circuits are grouped by function, and a specific troubleshooting approach is outlined for each circuit category. The book also lists proven component values the circuits, and includes suppliers of those components and their mailing addresses.

1000 AutoCAD Tips and Tricks: Third Edition; by George O. Head and Jan Doster Head. Ventana Press, P. O. Box 2468, Chapel Hill, NC 27515; Phone: 919-942-0220; Fax: 919-942-1140; $27.95.

This tips and tricks book is based on the authors' years of accumulated trial and error experience in working with AutoCAD. The book is organized into a compendium of practical techniques and shortcuts covering AutoCAD versions through Release 12. Arranged by skill level in "Beginning," "Intermediate," and "Advanced" sections, it offers useful advice on all the newest AutoCAD features.

For example, you'll learn how to use state-of-the-art dialog boxes for functions ranging from plotting to programming and how to



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manipulate new drafting tools such as grips and instant "hot" keys. The text explains how to pass information directly from AutoCAD to a database with Automatic Sequel Extension, and how to take advantage of the user-friendly features of the Windows version of AutoCAD. The book illustrates the creative use of AutoShade renderings and PostScript images inside the AutoCAD drawing and outputting to a variety of reader formats. Drawing and editing tips are included, and you'll learn about AutoLISP programs that speed up work, and 3D shortcuts and enhancements.

This third edition contains three new chapters that discuss AutoCAD release 12. They include hundreds of never-before published tips, and a new section filled with hints and tips for working with AutoCAD Windows. Purchasers of the book are eligible to receive two free newsletters that keep users informed on Autodesk updates.

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